

**Appendix E**

**Radionuclide Information Associated  
with the Amchitka, Alaska, Site**

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## E1.0 Introduction

This appendix provides information about radionuclides in the Amchitka test cavities that could potentially migrate from the Amchitka test cavities and various media. Table E-1, Potential Radionuclide Source Term and Pattern of Distribution in Test Cavities, lists these radionuclides with decay and partitioning<sup>1</sup> information.

## E2.0 Parameter Justification

Radionuclides considered candidates for sampling (from Table E-1) are listed in Table E-2, Radionuclide Justification. The intent of Table E-2 is to present considerations about whether a radionuclide should be considered for sampling and the rationale (Column 3). Recommendations are in Column 2. Retained means the radionuclide is considered for sampling. A not retained for sampling means that some of the radionuclides may provide useful information in combination with other isotopes or elements, but were not retained for sampling at this time.

The following established criteria are important to the evaluation of Amchitka sites:

- Half-life ( $T_{1/2}$ ) greater than 30 years except for  $^3\text{H}$ ,  $^{60}\text{Co}$ ,  $^{113\text{m}}\text{Cd}$ ,  $^{152}\text{Eu}$ , and  $^{90}\text{Sr}$  as noted (Cannikin was the last underground detonation on Amchitka on November 6, 1971).
- Does the radionuclide contribute a potential or significant dose to humans consuming food from the Amchitka marine environment? The following references were used:
  - Consortium for Risk Evaluation with Stakeholder Participation II, 2006. Amchitka Independent Sciences Assessment: Biological and Geophysical Aspects of Potential Radionuclide Exposure in the Amchitka Marine Environment.
  - Arctic Monitoring and Assessment Program, 2002. Arctic Pollution 2002, Persistent Organic Pollutants, Heavy Metals, Radioactivity, Human Health Changing Pathways.
  - Arctic Nuclear Waste Assessment Program, 1997. Radionuclides in the Arctic Seas from the Former Soviet Union: Potential Health and Ecological Risks.
- Does a suitable analytical technique exist to detect if an anthropogenic radionuclide is contributing to the natural environment from (1) Amchitka testing, (2) global fallout, or (3) nuclear fuel-cycle sources?
- Is the detected radionuclide associated with a nuclear detonation or the nuclear fuel cycle, and is the radionuclide distinguishable from natural background?
- Does the radionuclide bioconcentrate so as to contribute significant dose to the biota monitored?
- For nonbiota, is the radionuclide detectable above the natural background levels using current analytical techniques; does it have a sorption coefficient showing the potential to concentrate?

Daughter products of radionuclides are excluded from column 1 (Table E-2) except for  $^{241}\text{Am}$ .

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<sup>1</sup> Partitioning is the distribution of radionuclides between water, gas, and solid (rubble and lava) phases.

Figure E-1. Potential Radionuclide Source Term and Pattern of Distribution in Test Cavities  
(Adapted from IAEA 1998 and Smith et al. 2005)

Element Name	Symbol	Half-Life, Years	Main Decay Mode	Production Mode	Lava Distribution (TBq)	Rubble Distribution (TBq)	Gas Distribution (TBq)	Water Distribution (TBq)	Total (TBq)	% of Total
Americium	<sup>241</sup> Am	432	α	Fuel residue & product	370	10	0	0	380	0.122
Cadmium	<sup>113m</sup> Cd	14.1	β	Fission product	2.3	1	0	0	3.3	0.001
Calcium	<sup>41</sup> Ca	1.03 × 10 <sup>5</sup>	ec	(n, gamma) in environment	0.9	0.4	0	0	1.3	>0.0001
Carbon	<sup>14</sup> C	5,730	β	(n,p) in device	0	1	22	3	28	0.009
Cesium	<sup>135</sup> Cs	2.30 × 10 <sup>6</sup>	β	Fission product	0.06	0.21	0	0	0.27	>0.0001
Cesium	<sup>137</sup> Cs	30.1	β	Fission product	4,300	10,500	0	0	14,800	4.735
Chloride	<sup>36</sup> Cl	3.01 × 10 <sup>5</sup>	β	(n, gamma) in device & environment	0.9	0.7	0	0.1	1.7	0.001
Cobalt	<sup>60</sup> Co	5.27	β	(n, gamma) in device	2,300	300	0	0	2,600	0.832
Europium	<sup>152</sup> Eu	13.5	ec	(n, gamma) in environment	310	20	0	0	330	0.106
Europium	<sup>154</sup> Eu	8.59	β	Fission product and (n, gamma) in environment	47	3	0	0	50	0.016
Europium	<sup>155</sup> Eu	4.76		Fission product	450	20	0	0	0.14	0.000
Hydrogen	<sup>3</sup> H	12.3	β	Fuel residue & product	0	0	6,000	274,000	280,000	89.585
Iodine	<sup>129</sup> I	1.57 × 10 <sup>8</sup>	β	Fission product	0.003	0.0024	0	0.0006	0.0061	>0.0001
Krypton	<sup>85</sup> Kr	10.8	β	Fission product	0	100	800	100	1,000	0.320
Neptunium	<sup>237</sup> Np	2.14 × 10 <sup>6</sup>	α	Fuel residue & product	0.23	0.02	0	0	0.25	>0.0001
Nickel	<sup>59</sup> Ni	7.60 × 10 <sup>4</sup>	ec	(n, gamma) in device	3.6	0.2	0	0	3.8	0.001
Nickel	<sup>63</sup> Ni	100	β	(n, gamma) in device	430	20	0	0	450	0.144
Palladium	<sup>107</sup> Pd	6.50 × 10 <sup>6</sup>	β	Fission product	0.15	0.06	0	0	0.21	>0.0001
Plutonium	<sup>238</sup> Pu	87.7	α	Fuel product	185	5	0	0	200	0.064
Plutonium	<sup>239</sup> Pu	2.41 × 10 <sup>4</sup>	α	Fuel residue & product	1,080	20	0	0	1,100	0.352
Plutonium	<sup>240</sup> Pu	6,530	α	Fuel residue & product	295	5	0	0	300	0.096
Plutonium	<sup>241</sup> Pu	14.3	α	Fuel residue & product	67,000	100	0	0	0.0092	>0.0001
Plutonium	<sup>242</sup> Pu	3.73 × 10 <sup>5</sup>	α	Fuel product	0.009	0.0002	0	0	0.0092	>0.0001
Samarium	<sup>151</sup> Sm	90.0	β	Fission product	480	20	0	0	500	0.160
Selenium	<sup>79</sup> Se	1.10 × 10 <sup>6</sup>	β	Fission product	0.008	0.003	0	0	0.0011	>0.0001
Strontium	<sup>90</sup> Sr	28.8	β	Fission product	4,300	6,500	0	0	10,800	3.455
Technetium	<sup>99</sup> Tc	2.11 × 10 <sup>5</sup>	β	Fission product	2	0.5	0	0	2.5	0.001
Tin	<sup>121m</sup> Sn	55.0	IT	Fission product	0.22	0.14	0	0	0.36	>0.0001
Tin	<sup>126</sup> Sn	~1 × 10 <sup>4</sup>	β	Fission product	0.13	0.05	0	0	0.18	>0.0001
Uranium	<sup>236</sup> U	2.34 × 10 <sup>7</sup>	α	Fuel residue & product	0.12	0.02	0	0	0.14	>0.0001
Zirconium	<sup>93</sup> Zr	1.53 × 10 <sup>6</sup>	β	Fission product	0.3	0.02	0	0	0.32	>0.0001

Figure E-2. Radionuclide Justification

Element Symbol	Status	Rationale
Americium ( <sup>241</sup> Am)	Retained <sup>a</sup>	Major ingrowth of <sup>241</sup> Am from the decay of <sup>241</sup> Pu in the next 40 years and its high particle reactivity and BCF for mollusk remain a food web concern for monitoring.
Cadmium ( <sup>113m</sup> Cd)	Not Retained	Minor component of total radionuclide activity presented in Table E-1. Any leakage could not be easily detected. Some <sup>113m</sup> Cd is also present in the marine environment from atmospheric nuclear testing and nuclear fuel cycles. Low health risk from leakage.
Calcium ( <sup>41</sup> Ca)	Not Retained	Minor component of total radionuclide activity presented in Table E-1. Any leakage input could not be easily picked out from large background source of <sup>41</sup> Ca from atmospheric nuclear testing and natural atmospheric production. Low health risk from leakage.
Carbon ( <sup>14</sup> C)	Not Retained <sup>b</sup>	Minor component of total radionuclide activity presented in Table E-1. Any leakage could not be easily picked out from large background source of <sup>14</sup> C from atmospheric nuclear testing and natural atmospheric production. Low health risk from leakage.
Cesium ( <sup>135</sup> Cs)	Not Retained	Minor component of total radionuclide activity presented in Table E-1. Any leakage could not be easily detected. Some <sup>135</sup> Cs is also present in the marine environment from atmospheric nuclear testing and nuclear fuel cycles. Low health risk from leakage.
Cesium ( <sup>137</sup> Cs)	Retained	In saline groundwaters, such as those expected at Amchitka and in the marine environment, <sup>137</sup> Cs may move readily in the environment. Cesium-137 has BCFs for marine fish that range from 10 to 300 and is typically one of the principal current radionuclides contributing a significant portion of the man-made dose to consumers of marine foods.
Chloride ( <sup>36</sup> Cl)	Not Retained	Minor component of total radionuclide activity presented in Table E-1. Any leakage could not be easily picked out from large background source of <sup>36</sup> Cl from atmospheric nuclear testing and natural atmospheric production. Low health risk from leakage.
Cobalt ( <sup>60</sup> Co)	Not Retained	Cobalt-60 is an activation product created by underground nuclear tests, atmospheric nuclear tests, and the nuclear fuel cycle. It has been over 6-half-lives since the Cannikin nuclear test, and levels of <sup>60</sup> Co in any cavity water or leakage are very low and likely undetectable. It is included in a gamma spectroscopy analysis of environmental media along with other gamma-emitting radionuclides that are stored in the instrument gamma library and within the instrument calibration.
Europium ( <sup>150</sup> Eu)	Not Retained	Minor component of total radionuclide activity presented in Table E-1. Any leakage could not be easily detected. Some <sup>150</sup> Eu is also present in the marine environment from atmospheric nuclear testing and nuclear fuel cycles. Low health risk from leakage.
Europium ( <sup>151</sup> Eu)	Not Retained	Minor component of total radionuclide activity presented in Table E-1. Any leakage could not be easily detected. Some <sup>151</sup> Eu is also present in the marine environment from atmospheric nuclear testing and nuclear fuel cycles. Low health risk from leakage.
Europium ( <sup>152</sup> Eu)	Not Retained	Minor component of total radionuclide activity presented in Table E-1. Any leakage could not be easily detected. Some <sup>152</sup> Eu is also present in the marine environment from atmospheric nuclear testing and nuclear fuel cycles. Low health risk from leakage.
Hydrogen ( <sup>3</sup> H)	Retained	Tritium is produced in nuclear detonations in large quantities. Has the highest activity of any radionuclide present with a half-life greater than 10 years for a period of 100 to 200 years after an underground nuclear detonation. Moves readily with groundwater and, if found above background levels in marine water adjacent to Amchitka, would provide potential evidence of leakage from the nuclear tests.
Iodine ( <sup>129</sup> I)	Not Retained	Iodine-129 is naturally produced at low levels, but is also a nuclear fission product dispersed globally throughout the oceans due to nuclear testing and the nuclear fuel cycle; has been used to study travel of various point discharge sources, such as the European nuclear reprocessing facilities. Seawater levels of <sup>129</sup> I from nuclear-related activities, while at very low levels in marine waters, concentrate readily in macroalgae. The ratio of <sup>129</sup> I to <sup>127</sup> I (a stable isotope of I) from samples of macroalgae has been used in previous Arctic assessments to try to distinguish man-made sources from natural sources.
Krypton ( <sup>85</sup> Kr)	Not Retained	Principally present as a gas. While a potential inhalation hazard, much of the <sup>85</sup> Kr has diffused into the environment from nuclear testing. Does not readily bioconcentrate.
Neptunium ( <sup>237</sup> Np)	Not Retained	Plutonium isotopes, in particular the <sup>240</sup> Pu/ <sup>239</sup> Pu ratio, but also the other plutonium isotopes, and <sup>237</sup> Np and uranium isotopes occur in specific elemental and isotopic ratios that reflect their method of production, such as nuclear weapons testing or nuclear fuel cycle.
Nickel ( <sup>59</sup> Ni)	Not Retained	Minor component of total radionuclide activity presented in Table E-1. Any leakage could not be easily detected. Some <sup>59</sup> Ni is also present in the marine environment from atmospheric nuclear testing and natural fuel cycles. Low health risk from leakage.
Nickel ( <sup>63</sup> Ni)	Not Retained	Minor component of total radionuclide activity presented in Table E-1. Any leakage could not be easily detected. Some <sup>63</sup> Ni is also present in the marine environment from atmospheric nuclear testing and natural fuel cycles. Low health risk from leakage.
Palladium ( <sup>107</sup> Pd)	Not Retained	Minor component of total radionuclide activity presented in Table E-1. Any leakage could not be easily detected. Some <sup>107</sup> Pd is also present in the marine environment from atmospheric nuclear testing and nuclear fuel cycles. Low health risk from leakage.
Plutonium ( <sup>238</sup> Pu)	Retained for	Plutonium isotopes, in particular the <sup>240</sup> Pu/ <sup>239</sup> Pu ratio, but also the other plutonium isotopes,

Table E-2 (continued). Radionuclide Justification

Plutonium ( <sup>239</sup> Pu)	<sup>240</sup> Pu/ <sup>239</sup> Pu ratio	and <sup>237</sup> Np and uranium isotopes occur in specific elemental and isotopic ratios that reflect their method of production, such as nuclear weapons testing or nuclear fuel cycle.
Plutonium ( <sup>240</sup> Pu)		
Plutonium ( <sup>241</sup> Pu)	Not Retained	Minor production in nuclear tests, and any leakage could not be easily detected. Some <sup>241</sup> Pu is also present in the marine environment from atmospheric nuclear testing and nuclear fuel cycles. Low health risk from leakage.
Plutonium ( <sup>242</sup> Pu)	Not Retained	Minor production in nuclear tests, and any leakage could not be easily detected. Some <sup>242</sup> Pu is also present in the marine environment from atmospheric nuclear testing and nuclear fuel cycles. Low health risk from leakage.
Samarium ( <sup>151</sup> Sm)	Not Retained	Minor component of total radionuclide activity presented in Table E-1. Any leakage could not be easily detected. Some <sup>151</sup> Sm is also present in the marine environment from atmospheric nuclear testing and nuclear fuel cycles. Low health risk from leakage.
Selenium ( <sup>79</sup> Se)	Not Retained	Minor component of total radionuclide activity presented in Table E-1. Any leakage could not be easily detected. Some <sup>79</sup> Se is also present in the marine environment from atmospheric nuclear testing and natural fuel cycles. Miniscule amounts present compared with natural selenium isotopes in the environment. Low health risk from leakage.
Strontium ( <sup>90</sup> Sr)	Not Retained	Strontium, an anion, generally is more soluble in water than <sup>137</sup> Cs, but in saline groundwaters both these radionuclides may readily move with the groundwater. Once in the marine environment <sup>90</sup> Sr is harder to test for, due to partitioning factors, biological concentration factors, and analytical techniques. During the CRESP study results for all 85 biota samples analyzed for <sup>90</sup> Sr were below the method detection level. In other previous studies it has also been only occasionally detected.
Technetium ( <sup>99</sup> Tc)	Not Retained	Technetium-99 is produced from the fission of <sup>238</sup> U and <sup>239</sup> Pu during nuclear detonations and is present in the environment from nuclear weapons and fuel-cycle releases and is also in the Amchitka test cavities. Generally, moves readily with the groundwater. Macroalgae and certain crustaceans are known to have high bioconcentration factors (BCFs) for <sup>99</sup> Tc. Principal input to the environment is currently from nuclear reprocessing facilities in Europe and not to the Pacific or Arctic Oceans.
Tin ( <sup>121m</sup> Sn)	Not Retained	Minor component of total radionuclide activity presented in Table E-1. Any leakage could not be easily detected. Some <sup>121m</sup> Sn is also present in the marine environment from atmospheric nuclear testing and nuclear fuel cycles. Low health risk from leakage.
Tin ( <sup>126</sup> Sn)	Not Retained	Minor component of total radionuclide activity presented in Table E-1. Any leakage could not be easily detected. Some <sup>126</sup> Sn is also present in the marine environment from atmospheric nuclear testing and nuclear fuel cycles. Low health risk from leakage.
Total Uranium	Retained <sup>c</sup>	Provides no information on uranium isotopes present and cannot be used to help identify the source. Analytical techniques proposed have minimum detection concentrations (MDCs) typically above the levels expected in seawater and sediments from natural uranium. Mass of uranium isotopes produced in the nuclear detonation are extremely small and masked by naturally occurring uranium.
Uranium ( <sup>232</sup> U)	Not Retained	Uranium may be present in nuclear devices as weapon grade uranium (>90% <sup>235</sup> U) and also as depleted uranium (IAEA 1998). Uranium isotopes <sup>234</sup> U, <sup>235</sup> U, <sup>236</sup> U, and <sup>238</sup> U are produced or remain as residual process materials in only very small amounts as a result of a nuclear detonation compared to the larger quantities occurring naturally in the surrounding volcanic materials. Uranium-236 occurs naturally only in extremely small amounts and is principally produced in nuclear weapon detonations or in the fuel cycle. Under certain biogeochemical conditions the isotopes may move readily with the groundwater, and the ratios between specific isotopes can be applied to assessing leakage of radionuclides from the underground tests at Amchitka.
Uranium ( <sup>233</sup> U)		
Uranium ( <sup>234</sup> U)		
Uranium ( <sup>235</sup> U)		
Uranium ( <sup>236</sup> U)		
Uranium ( <sup>238</sup> U)		
Zirconium ( <sup>93</sup> Zr)	Not Retained	Minor component of total radionuclide activity presented in Table E-1. Any leakage could not be easily detected. Some <sup>93</sup> Zr is also present in the marine environment from atmospheric nuclear testing and nuclear fuel cycles. Low health risk from leakage.

BCF: Bioconcentration factor

<sup>a</sup>Retained: Included for sampling.

<sup>b</sup>Not Retained: Not included for sampling because considered to not represent any significant risk to human or other organisms and is not critical to determine if leakage is occurring.

<sup>c</sup>Retained: See Section 4.2.3.1 for rationale included for sampling.

## E2.1 Radionuclides Contributing to Human and Ecological Dose in the Marine Environment

Over the past 10 years numerous screening analyses have assessed principal radionuclides of concern from an overall release, a source identification perspective, and a human ecological viewpoint in the Arctic and tropical marine environments as a result of nuclear testing and dumping of nuclear wastes in the ocean (Layton et al. 1997; Sjoebloom K-L et al. 1997; AMAP 1998; IAEA 1998; Brungot et al. 1999; Nies et al. 1999; Efurud et al. 2000; AMAP 2004; CRESF 2006).

Most of these studies conclude that in the Arctic marine environment,  $^{137}\text{Cs}$ ,  $^{90}\text{Sr}$ ,  $^{241}\text{Am}$ , and  $^{239+240}\text{Pu}$  contribute most of the potential human dose via the subsistence-based human food web. For these radionuclides,  $^{137}\text{Cs}$ , followed by  $^{90}\text{Sr}$ , contributes the majority of the current dose;  $^{241}\text{Am}$  and  $^{239+240}\text{Pu}$  contribute to future dose (Layton et al. 1997; AMAP 1998 and 2002; IAEA 1998; Efurud et al. 2000).

## E2.2 Underground Nuclear Test Hydrological Source Term and Release Radionuclides

Radionuclides remaining after an underground nuclear test are from (IAEA 1998; Smith et al. 2003):

- Residual nuclear weapon fuel materials,
- Reaction products of the fuel materials,
- Fission products,
- Activation of non-fuel bomb components, and
- Activation products from construction materials and rock surrounding the explosion.

Tritium ( $^3\text{H}$ ),  $^{137}\text{Cs}$ ,  $^{90}\text{Sr}$ ,  $^{241}\text{Pu}$ ,  $^{152}\text{Eu}$ ,  $^{151}\text{Sm}$ , and  $^{154}\text{Eu}$ , in the preceding order, contributed the most amount of radioactivity out of 43 radionuclides selected to comprise long-lived potentially mobile and toxic radionuclides resulting from 828 underground nuclear tests at the U.S. Department of Energy (DOE) Nevada Test Site (NTS) through 1992 (Smith et al. 2003). This estimate is compared to the total inventories determined from the 1996 French underground nuclear tests at Fangataufa Atoll in the South Pacific (IAEA 1998). The French inventory (listed here from high to low) is:  $^3\text{H}$ ,  $^{137}\text{Cs}$ ,  $^{90}\text{Sr}$ ,  $^{60}\text{Co}$ ,  $^{239}\text{Pu}$ ,  $^{85}\text{Kr}$ ,  $^{151}\text{Sm}$ ,  $^{63}\text{Ni}$ , and  $^{241}\text{Am}$ . The differences are presumed to be due to the methods and algorithms used to calculate the inventory.

Candidate radionuclides monitored for nuclear proliferation purposes are:  $^3\text{H}$ ,  $^{90}\text{Sr}$ ,  $^{95}\text{Nb}$ ,  $^{95}\text{Zr}$ ,  $^{99}\text{Tc}$ ,  $^{106}\text{Ru}$ ,  $^{125}\text{Sb}$ ,  $^{134}\text{Cs}$ ,  $^{137}\text{Cs}$ ,  $^{144}\text{Ce}$ ,  $^{147}\text{Pm}$ , natural U,  $^{235}\text{U}$ ,  $^{237}\text{U}$ ,  $^{239}\text{Pu}$ ,  $^{240}\text{Pu}$ , and  $^{241}\text{Pu}$  (Wogman et al. 2000). Removing those with half-lives less than 6 years ( $^{134}\text{Cs}$ ,  $^{95}\text{Nb}$ ,  $^{95}\text{Zr}$ ,  $^{106}\text{Ru}$ ,  $^{125}\text{Sb}$ ,  $^{144}\text{Ce}$ ,  $^{147}\text{Pm}$ ) produces the unranked group  $^3\text{H}$ ,  $^{90}\text{Sr}$ ,  $^{241}\text{Pu}$ ,  $^{240}\text{Pu}$ ,  $^{239}\text{Pu}$ ,  $^{238}\text{Pu}$ ,  $^{106}\text{Ru}$ ,  $^{137}\text{Cs}$ ,  $^{129}\text{I}$ , and U series, which is somewhat similar to the NTS and French test site lists.

## E3.0 Discussion of Radionuclide Selections

### E3.1 Tritium ( $^3\text{H}$ )

*Description:* Tritium is produced naturally by nuclear reactions in the upper atmosphere as cosmic rays interact with atoms of nitrogen and oxygen (Gäggler 1995). Natural production of  $^3\text{H}$  in rainfall is approximately 0.118 becquerel/liter (Bq/L) (IAEA 2006). Atmospheric testing of nuclear devices adds  $^3\text{H}$  to the environment. In nuclear reactions, both from nuclear explosions and controlled processes in nuclear reactors,  $^3\text{H}$  is produced in significant quantities. Tritium is produced in nuclear detonations from direct use as a device component and from production the nuclear reactions associated with the detonation (Smith et al. 2003). Tritium is produced in large amounts during a nuclear test and readily moves with the groundwater. If leakage from the underground nuclear tests at Amchitka was occurring, this would be one of the first radionuclides expected to be identified. Leakage into the littoral and sublittoral zone would add  $^3\text{H}$  in excess of that naturally produced in the atmosphere and deposited in marine and fresh water.

For a period of 100 to 200 years after an underground nuclear detonation, tritium has the highest activity of any radionuclide with a half-life greater than 10 years (Smith et al. 2003; Efurud 1997). Unclassified estimates of the inventory of radionuclides remaining in the NTS underground tests in 1992 for  $^3\text{H}$  was  $4.65 \times 10^6$  terabecquerels (TBq), out of a total of  $4.86 \times 10^6$  TBq for 43 radionuclides, including  $^3\text{H}$  (Smith et al. 2003). One contaminant transport model provided a very conservative estimate of several hundred cubic meters of groundwater being discharged from the Milrow underground nuclear tests with  $^3\text{H}$  in excess of  $3.7 \times 10^7$  millibecquerels per liter (mBq/L) to the marine environment (Essington and Nork 1969). However, flow and transport results (Hassan and Chapman 2006), which use data from the recent CRESO study (CRESO 2005), show no tritium “breakthrough” to the marine environment in 2,000 years.

At the three Amchitka test watersheds, identified or inferred faults may project into the marine environment and could create leakage pathways.

Analytical detection levels for tritium in marine waters are on the order of 40 mBq/L (approximately 200 mBq/L is the EPA-Las Vegas laboratory MDC). Of all the potential radionuclides that could accompany  $^3\text{H}$  in any discharge, such as  $^{22}\text{Na}$ ,  $^{129}\text{I}$ , or  $^{99}\text{Tc}$ , only  $^3\text{H}$  has the potential to be detected even after several-thousand-fold dilution in ocean water.

The EPA-Las Vegas laboratory regularly conducts analysis for  $^3\text{H}$  by enrichment methods adequate to detect low levels in the marine environment. The EPA laboratory has the capacity to analyze large numbers of samples and has experience analyzing water samples with high levels of  $^3\text{H}$ . Other government or university laboratories generally are not set up to handle a high volume of samples, and in some cases prefer not to handle any sample that may have  $^3\text{H}$  in excess of natural background concentrations. The volume of water needed per sample is in the 0.5-liter to 1-liter range.

Tritium is completely soluble in water, and approximately 98 percent of the tritium in the test cavity is estimated to be in the water phase as tritiated water (IAEA 1998). Movement of tritiated water into and out of biological tissue is governed by an organism’s metabolism. Because of this, tritium does not biomagnify and usually has a bioconcentration factor (BCF) of 1.

*Relevance:* Tritium, during the first 100 years of DOE's long-term surveillance and monitoring program, is the radionuclide to regularly monitor in seawater for direct indication of potential leakage from the underground tests. Its biomagnification factor of 1 (IAEA 1995) and the difficulty of monitoring biota for tissue-bound tritium leads to the conclusion that monitoring tritium in biota is not practicable.

*Limitations:* There are no significant limitations for testing  $^3\text{H}$  in marine waters. Careful techniques are required for low-level detection.

*Analytical Technique:* For low-level analyses, the enriched  $^3\text{H}$  method is commonly used.

*Recommendation:* Tritium is retained for sampling for in the adjacent Amchitka marine waters at selected sites. The duration of monitoring should be based on the assumed size of the source since the quantity of tritium from the detonation is classified.

### **E3.2 Cesium-137 ( $^{137}\text{Cs}$ )**

*Description:* In nonsaline groundwaters,  $^{137}\text{Cs}$ , a cation, is a reactive species sorbing readily to geologic materials such as carbonates, but in waters of higher ionic strength, such as the brackish waters in the underground environments at Amchitka, Cs may act as a nonreactive species (Hassan et al. 2002). Generally, in typical marine waters containing little total suspended solids (especially clay particles or colloids), Cs is considered highly soluble (IAEA 2005).

$^{137}\text{Cs}$  has BCFs for marine fish that range from 10 to 300 (IAEA 1995). In the past 15 years, studies such as the Arctic Nuclear Waste Assessment Program (ANWAP) and the Arctic Monitoring and Assessment Program (AMAP) have documented that  $^{137}\text{Cs}$  is one of the principal radionuclides of concern in the marine food web contributing to human or ecological dose (Layton et al. 1997; Efurud et al. 2000; AMAP 1998; IAEA 2005).

*Limitations:* Due to the relatively low level of  $^{137}\text{Cs}$  in some sampling media such as macroalgae, sample collection volume and volume reduction are critical to detecting levels above instrument MDCs. Although the Consortium for Risk Evaluation with Stakeholder Participation (CRESP) sampling did not detect any  $^{137}\text{Cs}$  in macroalgae above the instrument MDCs,  $^{137}\text{Cs}$  was regularly detected by the EPA in 1997 and later the Alaska Department of Environmental Conservation studies in 1998 and 2001, principally because of adequate sample volume and processing.

*Analytical Technique:* Environmental low-level, high-resolution gamma spectroscopy combined with sufficient sample volume collected with resulting volume reduction before analysis. Another option is to concentrate Cs using radiochemistry to extract and concentrate the Cs from the sample.

*Recommendation:* Cesium is retained for sampling because of its ability to bioconcentrate in certain food web organisms such as fish and top predators, its general contribution to anthropogenic dose, and the fact that it can move conservatively in the underground saline or transient zone groundwaters and nearshore marine environment.

### E3.3 Strontium-90 ( $^{90}\text{Sr}$ )

*Description:* Strontium, an anion, is generally more soluble in water and is not as readily sorbed onto surrounding soil and rock as cationic species of radionuclides such as  $^{137}\text{Cs}$ . Based on some studies of  $^{90}\text{Sr}$  and  $^{137}\text{Cs}$  in saline groundwaters, both of these radionuclides can be considered to act conservatively. While dependent upon the weapon design, generally larger quantities of  $^{137}\text{Cs}$  are produced compared to  $^{90}\text{Sr}$  in underground nuclear detonations.

*Limitations:* Once in the marine environment, due to partitioning factors, BCFs ( $^{90}\text{Sr}$  BCF for fish is approximately 2, and  $^{137}\text{Cs}$  BCF for fish is approximately 100 [IAEA 1995]), and analytical technique difficulty (compared to Cs), many results are generally below the MDC. During the CRESP study, results for all 85 biota samples analyzed for  $^{90}\text{Sr}$  were below the method MDC (CRESP 2005).

$^{137}\text{Cs}$  contributes significantly more dose to biological organisms than  $^{90}\text{Sr}$ . This is due to the high-energy gamma ray from its daughter radionuclide and its distribution throughout the muscle tissue, whereas  $^{90}\text{Sr}$  decays by beta emission. For example, the estimated dose to subsistence users from  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  released from the nuclear waste dumping in the Arctic Ocean by the former Soviet Union are on the order of [XX and YY], respectively (Layton et al. 1995).

*Analytical Technique:* To be added at a later date.

*Recommendation:* For the above reasons,  $^{90}\text{Sr}$  is not retained for sampling.

### E3.4 Plutonium Isotopes ( $^{238}\text{Pu}$ , $^{239}\text{Pu}$ , $^{240}\text{Pu}$ , $^{241}\text{Pu}$ , $^{242}\text{Pu}$ ) and Neptunium-237 ( $^{237}\text{Np}$ )

*Description:* Plutonium isotopes, in particular the  $^{240}\text{Pu}/^{239}\text{Pu}$  ratio, but also the other plutonium isotopes, and  $^{237}\text{Np}$  and uranium isotopes occur in specific elemental and isotopic ratios that reflect their method of production, such as nuclear weapons testing or nuclear fuel cycle (Cooper et al. 2000). Previous studies (Efurd [to be supplied]; Dashier et al. 2000; Hamilton et al. 2004) have identified sources other than global atmospheric fallout that contribute excess  $^{240}\text{Pu}/^{239}\text{Pu}$  to the environment.

Based on other marine health and ecological risk evaluations, it is reasonable to speculate that the longer-lived plutonium isotopes such as  $^{239}\text{Pu}$  and  $^{241}\text{Am}$  (the longer-lived decay daughter of  $^{241}\text{Pu}$ ) could leak from the Amchitka underground test cavities and contribute the major long-term dose to biological organisms in the vicinity of Amchitka.

*Limitations:* Activity ratios between the plutonium isotopes, such as  $^{238}\text{Pu}$  (83-year half-life) can be used to help identify sources of plutonium isotopes by the use of  $^{238}\text{Pu}/^{239+240}\text{Pu}$  ratio.  $^{241}\text{Pu}$  may also be used in a similar fashion. In actual practice, the technique is of limited use at Amchitka, principally because the environmental levels observed are close to the MDC for typical alpha spectroscopy methods, and counting errors are large, producing significant uncertainties into ratio measurements (Cooper et al. 2000).

*Analytical Technique:* Thermal ionization mass spectroscopy, high-resolution inductively coupled plasma mass spectroscopy, and accelerator mass spectroscopy are highly sensitive

techniques that, when properly applied, yield precise estimates of isotopic ratios (Lee et al. 2000).

*Recommendation:* Because their specific concentrations and isotopic ratios may reflect the method of production, such as nuclear weapons testing or nuclear fuel cycle, plutonium isotopes,  $^{237}\text{Np}$ , and U isotopes may be utilized in the future but are not retained for sampling at this time.

### E3.5 Technetium-99 ( $^{99}\text{Tc}$ )

*Description:*  $^{99}\text{Tc}$  (212,000-year half-life) is produced from fission of  $^{235}\text{U}$  and  $^{239}\text{Pu}$  during nuclear detonations and is present in discharges from some nuclear facilities (Hirano et al. 1993). As an anion,  $^{99}\text{Tc}$  is considered conservative in groundwater and may even move at a higher rate than the bulk groundwater (Bryant 1992). The high solubility of  $^{99}\text{Tc}$  allows it to move rapidly in groundwater. The migration rate of  $^{99}\text{Tc}$  in some environments is expected to be very close to the velocity of groundwater unless it is reduced to a less-soluble form. In a reducing environment the geochemical form of  $^{99}\text{Tc}$  may not be as mobile as in a well-oxygenated environment, where it is present typically as the pertechnetate ion,  $\text{TcO}_4^-$  (Ikäheimonen et al. 2001).

Macroalgae and certain crustaceans are known to have high BCFs for  $^{99}\text{Tc}$ , but there remains a lack of knowledge of the biogeochemical cycling of  $^{99}\text{Tc}$  and uptake/effects in biological organisms (AMAP 2004).

Previous work in 2001 (unpublished) detected  $^{99}\text{Tc}$  concentrations in *Fucus disticus* of 0.255 becquerel/kilogram (Bq/kg) dry weight (d.w.)  $\pm$  20 percent near Cannikin and 0.183 Bq/kg d.w.  $\pm$  25 percent near Milrow. A background reference site at Summer Bay, near Unalaska, Alaska, had a value for *Fucus disticus* of 0.176 Bq/kg d.w.  $\pm$  23 percent. A crude estimate of  $^{99}\text{Tc}$  levels in North Pacific marine waters in the Aleutians, based on a BCF of 10,000 (Hirano et al. 1993), is approximately  $2.5 \times 10^{-6}$  Bq/kg.

*Limitations:*  $^{99}\text{Tc}$  is a concern to AMAP because it was discharged from the British Nuclear Fuels' Sellafield reprocessing facility into the Irish Sea, and from there it was transported to the coasts of Scandinavia (AMAP 2002). From 1994 to 1995, over 262 TBq of  $^{99}\text{Tc}$  was discharged to the Irish Sea (Brown et al. 1999). This is likely more than the total activity present in the three Amchitka test cavities. The estimated total  $^{99}\text{Tc}$  produced in the South Pacific French nuclear test site was only 2.5 TBq (IAEA 1998). Levels in *Fucus vesiculosus* near Norway in 1997 and 1998 ranged from 79 to 124 Bq/kg d.w. (Brown et al. 1998), which is significantly above the levels in *Fucus disticus* at Amchitka in 2001.

In 1998, the Norwegian Radiation Protection Authority observed that "...doses from human consumption of seafood from Norwegian waters are probably low due to the low levels of contamination and the low dose conversion factor of  $^{99}\text{Tc}$ " (AMAP 2002).

*Analytical Technique:* [To be added at a later date.]

*Recommendation:*  $^{99}\text{Tc}$  is produced from the fission of  $^{235}\text{U}$  and  $^{239}\text{Pu}$  during nuclear detonations and is present in the environment, including the Amchitka test cavities, from nuclear weapons and fuel-cycle releases. Generally,  $^{99}\text{Tc}$  moves readily with the groundwater. Macroalgae and certain crustaceans are known to have high BCFs for  $^{99}\text{Tc}$ . The principal input to the environment is currently from nuclear reprocessing facilities in Europe, and  $^{99}\text{Tc}$  from the

European facilities does not find its way to the Pacific or Arctic Oceans.  $^{99}\text{Tc}$  is not retained for sampling.

### E3.6 Iodine Isotopes ( $^{127}\text{I}$ , $^{129}\text{I}$ )

*Description:*  $^{129}\text{I}$  (15.7-million-year half-life) is a nuclear fission product dispersed globally throughout the oceans due to atmospheric nuclear testing and the nuclear fuel cycle.  $^{129}\text{I}$  has been used to study travel of various point discharge sources, such as the European nuclear reprocessing facilities (Cooper et al. 1998).  $^{129}\text{I}$  from nuclear-related activities, while at very low levels in marine waters, concentrates readily in kelp and reaches 5 orders of magnitude above the level in seawater (Cooper et al. 1998).

Very little  $^{129}\text{I}$  is produced naturally, and in pre-atomic-age samples of marine algae the ratio of  $^{129}\text{I}$  to  $^{127}\text{I}$  (a stable isotope of I) is on the order of  $1.92 \times 10^{-10} \pm 0.028$  to  $3.69 \times 10^{-10} \pm 0.024$ . One recent study suggested a  $^{129}\text{I}/^{127}\text{I}$  ratio of approximately  $10 \times 10^{-11}$  is close to the global fallout contribution to marine waters. Measurements of  $^{129}\text{I}/^{127}\text{I}$  ratios in kelp taken near Novaya Zemlya, an island in the Arctic Ocean used by the former Soviet Union for nuclear testing, were in the range of  $6.00 \times 10^{-9}$  to  $8.00 \times 10^{-9}$ . A sample from Adak Island, Alaska, had a ratio of  $1.754 \times 10^{-10} \pm 0.55$ .

*Limitations:* While the Scandinavian marine waters have slightly higher  $^{129}\text{I}$  levels, due to discharge from the British and French nuclear reprocessing facilities, the levels observed are an insignificant risk to human health (AMAP 2002).

*Analytical Technique:* [To be added at a later date.]

*Recommendation:*  $^{129}\text{I}$  is naturally produced at low levels and is also a nuclear fission product dispersed globally throughout the oceans due to nuclear testing and the nuclear fuel cycle. Seawater levels of  $^{129}\text{I}$  from nuclear-related activities, while at very low levels in marine waters, concentrate readily in macroalgae. The ratio of  $^{129}\text{I}$  to  $^{127}\text{I}$  (a stable isotope of I) from sampled macroalgae has been used in previous Arctic assessments to try to distinguish man-made sources from natural sources.  $^{129}\text{I}$  is not retained for sampling.

### E3.7 Uranium Isotopes ( $^{234}\text{U}$ , $^{235}\text{U}$ , $^{236}\text{U}$ , $^{238}\text{U}$ )

*Description:* Uranium may be present in nuclear devices as weapon grade uranium (greater than 90 percent  $^{235}\text{U}$ ) and also as depleted uranium (IAEA 1998). Generally, the uranium isotopes  $^{234}\text{U}$ ,  $^{235}\text{U}$ ,  $^{236}\text{U}$ , and  $^{238}\text{U}$  are produced or remain as residual process materials as a result of a nuclear detonation and are in very small amounts compared to the large quantities occurring naturally in the surrounding volcanic rock. For example, at the French nuclear test site in the South Pacific approximately 350 kg of highly enriched uranium was used in the underground nuclear tests versus 50 tons (45,350 kg) of natural uranium present in the volcanic rock of the shot cavities (IAEA 1998). The long half-lives of many of the uranium isotopes represent a low specific activity resulting in insignificant dose to the environment.

One aspect of the uranium isotopes particularly relevant to Amchitka is that under certain biogeochemical conditions they may move readily with the groundwater. The ratios between specific uranium isotopes can be applied to assessing leakage of radionuclides from the

underground tests at Amchitka. The reported natural uranium value for  $^{235}\text{U}/^{238}\text{U}$  is approximately  $7.25 \times 10^{-3}$  (Rosman et al. 1998) and has been used in evaluating pollution from enriched nuclear sources (Bellis et al. 2001).  $^{236}\text{U}$  (23.4 million-year half-life) occurs at extremely low levels in nature compared to  $^{238}\text{U}$ , and the ratio of  $^{236}\text{U}$  to  $^{238}\text{U}$  is approximately  $10^{-14}$  for natural conditions (Marsden et al. 2006). Neutron capture by  $^{235}\text{U}$  in nuclear reactors and detonations readily produces amounts of  $^{236}\text{U}$  above natural background levels and provides an indicator of the presence of anthropogenic uranium sources (Ketterner et al. 2003; Luis Mas et al. 2006). The ratio between anthropogenic  $^{236}\text{U}$  and the other uranium isotopes has potential to be useful to assess leakage from the Amchitka test and perhaps distinguish it from global fallout or other sources (Dresel et al. 2002).

*Limitations:* The MDC for the total U analytical method for seawater is about 500 picocuries per liter (pCi/L) (18.5 Bq/L). Total U observed in Pacific Ocean seawater is approximately 0.9 pCi/L (33 mBq/L).

*Recommendation:* U and U isotopes are not retained for sampling.

### **E3.8 Americium-241**

*Description:*  $^{241}\text{Am}$  is the result of the decay of its parent  $^{241}\text{Pu}$ . Most of the  $^{241}\text{Am}$  in Arctic Ocean seawater is a result of fallout from atmospheric nuclear testing conducted in the late 1950s and early 1960s (Layton et al. 1997).  $^{241}\text{Am}$  is highly particle reactive and has a sediment-water distribution coefficient ( $k_d$ ) of  $2,000 \text{ m}^3/\text{kg}$ .  $^{241}\text{Am}$  has BCFs on the order of  $0.05 \text{ m}^3/\text{kg}$  for fish and  $20 \text{ m}^3/\text{kg}$  for mollusk (IAEA 1985). With respect to complete pathways for biological organisms,  $^{241}\text{Am}$  does not have an elevated dose rate greatly above or below those of  $^{137}\text{Cs}$ ,  $^{90}\text{Sr}$ , or  $^{239+240}\text{Pu}$  (Layton et al. 1998). However, a pathway of concern in regard to biota is its particle reactive nature.  $^{241}\text{Am}$  can be easily incorporated into phytoplankton/zooplankton and sediments and is a BCF concern in mollusk.

*Limitations:* [To be added at a later date.]

*Analytical Information:* [To be added at a later date.]

*Recommendation:* Major ingrowth of  $^{241}\text{Am}$  from decay of  $^{241}\text{Pu}$  in the next 40 years and its high particle reactivity and BCF for mollusk remain a food web concern for monitoring.  $^{241}\text{Am}$  presents an internal and external exposure factor to invertebrates and mollusk filter feeders such as blue mussel or horse mussel.  $^{241}\text{Am}$  is retained for sampling.

## **E4.0 Media Selection**

It is important to sample both abiotic (nonliving) and biotic (living) media to monitor for radionuclides that could leak from the Amchitka cavities. However, current laboratory detection levels are generally not adequate to detect the radionuclide concentration levels in abiotic media (with the exception of  $^3\text{H}$ ) and are marginally adequate for biotic bioaccumulator media.

## E4.1 Abiotic (nonliving organisms)

Sediment is the best medium to make spatial comparisons between sites and monitoring projects (NOAA 1999). Because many radionuclides are particle reactive, sediments can be collected; however, current analytical MDCs are generally inadequate. Sediments can be archived for future radionuclide analysis if analytical techniques improve. Archived samples may be important to resolving issues raised by the *Mytilus* and *Fucus* analysis.

## E4.2 Biotic (living organisms)

Numerous marine monitoring programs evaluating radionuclides, trace elements, and organic contaminants have analyzed mussel and seaweed. Some of the advantages of their use are:

- Their sessile nature allows for long-term studies to be completed and trends in radionuclide levels to be identified.
- Biota can concentrate radionuclides from the ambient water.
- Biota may integrate radionuclides over time, even those whose levels may fluctuate widely in the water column.
- Food web transfer to predators can be estimated.
- Widespread monitoring of radionuclides with mussels, especially the blue mussel (*Mytilus spp.*) and brown seaweed (*Fucus spp.*), permits comparison of contaminant levels between different areas.

The following considerations are suggested to guide the process of species selection for sampling:

- Species selected must help assess human exposure to radionuclides associated with nuclear testing. The focus should be primarily on Aleut subsistence food and secondarily on commercial seafood species taken near Amchitka Island.
- Species selected should help assess ecological risk to the marine and coupled nearshore marine and terrestrial food web. Keystone species in apex animal food webs are important.
- Species selected must have the ability to concentrate radionuclides relevant to evaluating the possible origins of man-made radionuclides, that is, global fallout versus potential leakage from the underground tests, in the environment and around Amchitka Island.

The following documents were used to help assess and select the appropriate media that accumulate anthropogenic radionuclides, to help evaluate the potential origin of these radionuclides in the environment around Amchitka, and to help estimate health significance.

- *Biomonitoring for Ecosystem and Human Health Protection at Amchitka Island* (Burger et al. 2006).
- *Final Report for the Consortium for Risk Evaluation with Stakeholder Participation Amchitka Independent Science Assessment: Biological and Geophysical Aspects of Potential Radionuclide Exposure in the Amchitka Marine Environment* (Powers et al. 2006).

- *Subsistence Food Use in Unalaska and Nikolski* (APIA 2003).
- *Subsistence Food Use in Atka* (APIA 1999).
- *Amchitka, Alaska, Special Project Sampling Plan 1997—Sampling and Analysis Plan* (EPA 1997).
- *Amchitka and the Regional Foodweb* (Stout, J. 2002).
- ADF&G Subsistence Food Harvest Studies—Community Subsistence Info. System (<http://www.subsistence.adfg.stste.ak.us/CSIS>).
- *Amchitka Radiobiological Program—Final Report* July 1970 to December 1979 (Sibley et al. 1982).
- *Annual Progress Report—Radionuclide and Stable Element Analysis of Environmental Samples from Amchitka Island, Alaska* (Vogt et al. 1968).

Detailed discussion can be found in the current CRESP documents, much of it supported by the previous radiobiological sampling. Input from the regional Aleut communities has been especially valuable in assessing important subsistence foods to monitor.

An important consideration is that Aleut diet varies with seasonal and trading availability. Their trading network is highly efficient and results in transport of food into communities from remote sources. Research indicates that if the Aleuts were on Amchitka, and gull eggs, gumboots, or Dolly Varden and other subsistence species are in season, they will harvest that particular item and often trade with relatives on other islands. The means of gathering and division of food are based on Aleut tradition; for example, a sea lion is divided by hunter and helpers and families (Veltre and Veltre 1981).

Specific radionuclides will concentrate to varying degrees in different organisms and abiotic media. In assessing potential leakage from the Amchitka underground nuclear tests, one focus is on sessile species (relatively nonmobile) or species with limited ranges that potentially show increased levels of certain radionuclides, in certain ratios, or above the regional background for similar species. Species that range regionally in the larger ocean do not accumulate their principal radionuclide body burden from sources around Amchitka Island.

Based on the above technical considerations, suggested abiotic and biotic media for sampling are listed in Table E-3, Candidate Media Recommended for Sampling. Current radionuclide detection limits, sample archival, cost, and other practical considerations have not been properly factored into the recommendations in Table E-3.

Figure E-3. Candidate Media Recommended for Sampling

Sampled Media	Human Health	Leakage Assessment	Ecological Health	Comment
<b>Abiotic</b>				
Seawater		X	X	Tritium is easily sampled for in seawater. This is the principle medium for testing for <sup>3</sup> H, which in excess of background will provide evidence of potential leakage from the underground nuclear tests.
Marine Sediments		X	X	Marine sediments, if fine-grained, provide for integration over time of radionuclides, and through dated core samples one can determine if changes are occurring over time that might be missed by other sampling.
Freshwater	X			Shallow groundwater at the Long Shot test site contains residual <sup>3</sup> H from the test, and, while below EPA drinking water standards, continued confirmation of its decline is essential to people visiting and working on the island. Monitoring <sup>3</sup> H in groundwater is also relevant to the assessment of the concern with earthquake-induced leakage or fallout from any future nuclear incidents around the world. Freshwater remains to be harvested for drinking water during human habitation of the island or by vessels stopping by Amchitka.
Freshwater Sediments		X		Freshwater sediments contain a past record of global fallout and are monitored to detect potential earthquake-induced leakage and baseline changes due to future nuclear incidents around the world.
<b>Biotic</b>				
Macroalgae				
<i>Alaria f./Fucus d.</i>				These species concentrate various radionuclides of interest from the seawater for assessing activity and isotopic signatures for plutonium, uranium, and others to evaluate sources of man-made radionuclides. Radionuclides such as <sup>137</sup> Cs are also concentrated and are of interest in the human and ecological health assessment.
Organisms				
Sea Urchin	X		X	Sea urchins are grazers at the base of the food chain feeding principally on macroalgae and are of interest to both human and ecological health. Relevant to the sea otter food web.
Chiton (Gumboots)	X		X	Aleut subsistence food important to the human health assessment. It is also relevant to food web concentration of radionuclides because of its trophic niche grazing periphyton off the rocks and corals of the sea floor.
Blue Mussels (caged)	X	X	X	Blue mussels are the only filter feeders included here and provide important information on radionuclide concentrations on particulate and small organisms and plants in the water column. They also represent a concern in both the human and ecological health evaluation. A lack of adequate number of mussels for sampling resulted in the use of caged mussels for this sampling plan period.
Rock/Kelp Greenling	X		X	Rock and kelp greenling are sedentary, are an important component of the food web, and integrate radionuclides at a different trophic level than rockfish.
Black/Dusky Rockfish	X		X	Rockfish are sedentary, are an important component of the food web, and integrate radionuclides at a different trophic level than greenling.
Halibut	X		X	While not a local or sedentary fish, they may feed in the nearshore environment around Amchitka and are an important commercial and subsistence species.

Table E-3 (continued). Candidate Media Recommended for Sampling

Sampled Media	Human Health	Leakage Assessment	Ecological Health	Comment
<b>Biotic (continued)</b>				
Pacific Cod	X		X	While not a local or sedentary fish, they may feed in the nearshore environment around Amchitka and are an important commercial and subsistence species.
Silver Salmon	X		X	While not a local or sedentary fish, they may feed in the nearshore environment around Amchitka and are an important commercial and subsistence species.
Dolly Varden	X		X	Land-locked (Cannikin Lake) and sea run are important to sample as a local subsistence species and heavily fished for by contract employees when construction or cleanup programs have occurred on Amchitka.
Steller Sea Lion	X		X	Apex predator resident to Amchitka and is important as an Aleut native subsistence food. It is a protected species and, although samples provided by native subsistence hunters can be analyzed, it cannot be collected directly for radionuclide analysis.
Sea Gull Eggs	X		X	Concern because of subsistence use.
Samples of Opportunity	X	X	X	If a member of the public or an agency representative discovers animals that died or that exhibit unusual illness, and the animal is collected, there should be a procedure for archiving samples and prioritizing them for analysis to address public concern.

## E5.0 References

(Rewrite of Appendix F was furnished by ADEC in a letter to DOE-LM, Tracy Plessinger, January 2, 2007, with comments on the Draft Amchitka LTS&M Plan. The rewrite is adopted for Appendix F and replaces the original. Complete reference citations in Appendix F, were not provided by ADEC. The citations in the text are listed below.)

A/PIA 1999

A/PIA 2003

AMAP 1998

AMAP (Arctic Monitoring and Assessment Program) 2002. *Arctic Pollution 2002, Persistent Organic Pollutants, Heavy Metals, Radioactivity, Human Health Changing Pathways.*

AMAP 2004

ANWAP (Arctic Nuclear Waster Assessment Program) 1997. *Radionuclides in the Arctic Seas from the Former Soviet Union: Potential Health and Ecological Risks.*

Bartell et al. 1999

Bellis et al. 2001

Brown et al. 1998

Brown et al. 1999

Brungot et al. 1999;

Bryant 1992

Burger et al. 2006

Cooper et al. 1998

Cooper et al. 2000

CRESP 2005

CRESP (Consortium for Risk Evaluation with Stakeholder Participation II), 2006. *Amchitka Independent Sciences Assessment: Biological and Geophysical Aspects of Potential Radionuclide Exposure in the Amchitka Marine Environment.*

Dashier et al. 2000

Dresel et al. 2002

Efurd [to be supplied]

Efurd et al. 2000

Efurd 1997

EPA 1997

Essington and Nork 1969

Gäggler 1995

Hamilton et al. 2004

Hamrick et al. 2003

Hassan et al. 2002  
Hirano et al. 1993  
IAEA 1985  
IAEA 1995  
IAEA 1998  
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Ikäheimonen et al. 2001  
Ketterner et al. 2003  
Layton et al. 1995  
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